

PROJECT SUMMARY

NASA TASK ORDER 4 FINAL REPORT



TASK NO.: NNL10AB14T

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PROJECT TITLE:

Aerodynamic, Aerothermodynamic and Thermal Protection System integration module

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SUMMARY:

This report documents the work performed during from March 2010 – October 2011. The Integrated Design and Engineering Analysis (IDEA) environment is a collaborative environment based on an object-oriented, multidisciplinary, distributed environment using the Adaptive Modeling Language (AML) as the underlying framework. This report will focus on describing the work done in the area of extending the aerodynamics, and aerothermodynamics module using S/HABP, CBAERO, PREMIN and LANMIN. It will also detail the work done integrating EXITS as the TPS sizing tool.

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Date:

November 10, 2011



Final Report
Integrated Design Engineering Analysis (IDEA) environment
Aerodynamics, Aerothermodynamics, and Thermal Protection
System integration module

Contract Number: NNL09AA10B / Task: NNL10AB14T

Report Prepared: October 2011

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Introduction

The Integrated Design and Engineering Analysis (IDEA) environment is a collaborative environment based on an object-oriented, multidisciplinary, distributed framework using the Adaptive Modeling Language (AML). IDEA has several modules that integrate different aerodynamics, and aerothermal analysis codes. Thus far, the following aerodynamic analysis codes have been fully integrated:

1. AWAVE
2. DATCOM
3. APAS
4. S/HABP
5. S/HABP for computing the aerodynamic derivatives
6. CBAERO

The appropriate discrete representations of the geometry are generated automatically if one of the basic configuration models is used to perform the analysis, otherwise a set of tools within IDEA can be used to build the discrete representation interactively. All the geometric and non-geometric data needed to execute these codes are GENERATIVELY (no need for a preexisting template) created, and the post processing of the results from visualization to interpreting and passing the results to the different disciplines is done within IDEA in a seamless fashion, and with minimal user interaction.

There are four top level classes in IDEA that can be used to model and analyze vehicle configurations within the IDEA environment. These classes are:

1. *nasa-tsto-upper-configuration-type-2-class*
2. *space-vehicle-from-imported-geometry-type-1-class*
3. *nasa-tsto-first-stage-hypersonic-configuration-type-1-class*
4. *space-vehicle-air-breather-configuration-from-imported-geometry-type-1-class*

By selecting one of these representative classes within the IDEA environment, the user creates a set of objects that can be used for aerodynamic analysis, aerothermal analysis, configuration management, trajectory analysis, and structural analysis. Figure 1 illustrates the tree structure generated by expanding an instance of *nasa-tsto-upper-configuration-type-2-class*.

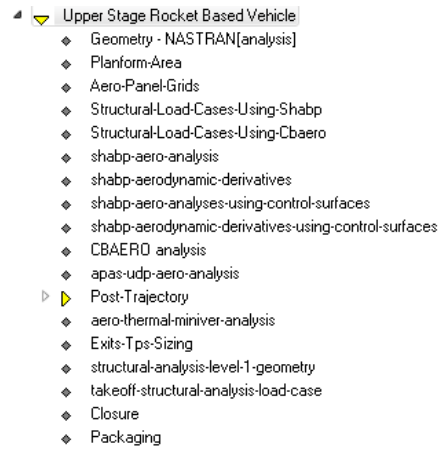


Figure 1. Tree structure associated with *nasa-tsto-upper-configuration-type-2-class* instance

Control surface deflections

IDEA has been extended to handle the creation and deflection of control surfaces for wings and tails, allowing the user to perform what-if studies to determine the required control surface locations and sizes. The user can specify an independent deflection schedule for each control surface. At this point, a series of control surface grids that corresponds to the deflection angle schedule is generated and is used for analysis. Figure 2 illustrates the geometry associated with control surfaces. The user can specify the size of the control surfaces by specifying the percent chord and percent span for each wing/tail planform as illustrated in Figure 2.

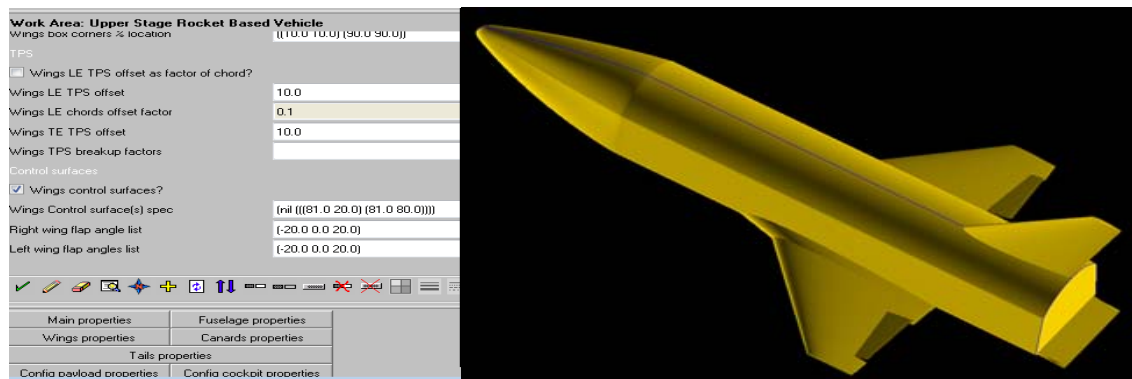


Figure 2. Winged vehicle with control surfaces defined.

The user can also specify the deflection angle schedule associated with the right and left wings separately. The generated geometries are high fidelity geometries and are suitable for meshing and analysis. In Figure 3, the geometry from Figure 1 is used to build an unstructured tri-mesh that is suitable for use in CBAERO and CART3D.

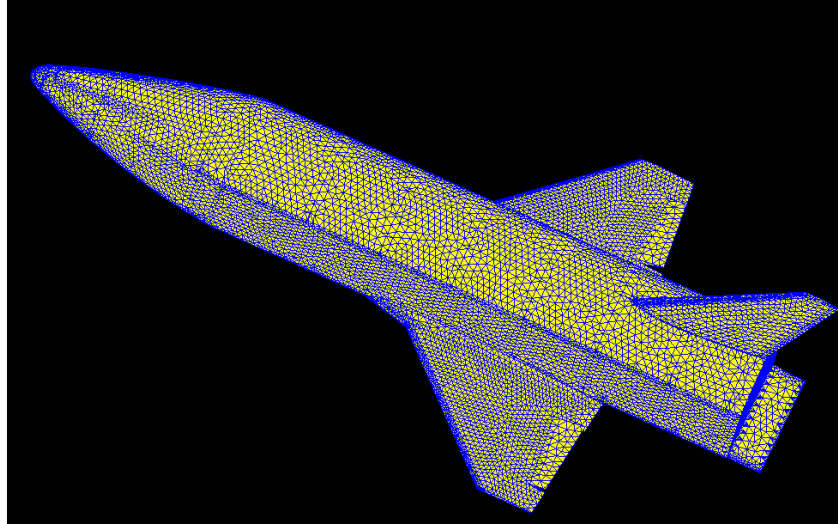


Figure 3. Unstructured tri-mesh with control surfaces.

The different regions of the geometry are tagged with different attributes. The attributes propagate to the mesh and the mesh can be queried to extract the elements and nodes that lie in the different regions. Figure 4 illustrates the tagged regions each with its unique color.

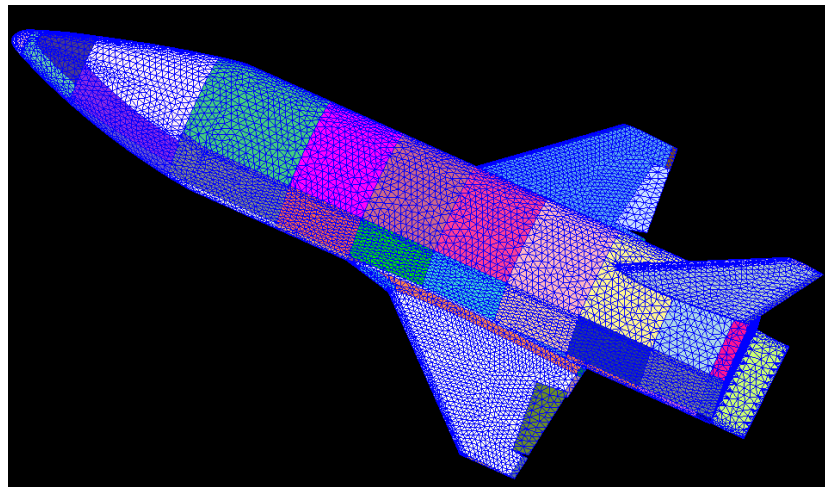


Figure 4. Regions tagged with unique IDs.

The environment automatically builds an aero panel mesh suitable for running APAS, and S/HABP. Figure 5 illustrates an automatically generated aero-panel mesh.

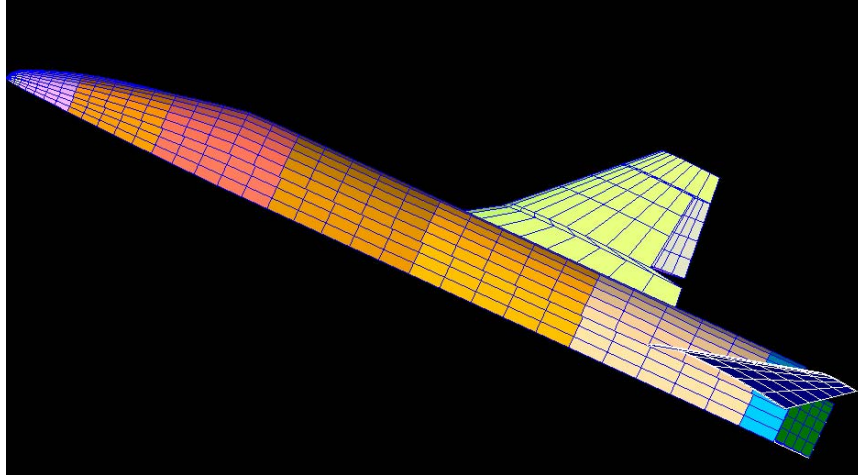


Figure 5. Aero-panel mesh suitable for APAS and S/HABP, including control surface deflection.

The generated meshes are used to run different analysis codes to capture the heating environment to be used by the TPS sizing codes.

Aerothermal environment

IDEA has been updated to allow the user to run S/HABP, CBAERO, and/or PREMIN/LANMIN and capture the aerothermal environment associated with the vehicle and trajectory. The data generated by these codes is then input into EXITS (TPS sizing code) which provides the TPS weights and TPS performance data.

S/HABP

The S/HABP integration was updated to allow the user to run viscous level II analysis and generate heat loads required by EXITS. To run viscous level II analysis, QuadStream was integrated allowing for the generation of the streamlines from the aero-panel grids as depicted in Figure 6.

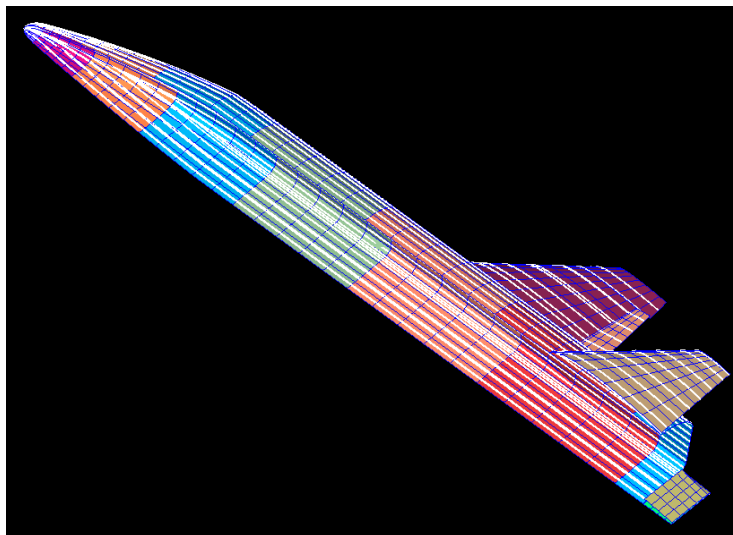


Figure 6. Aero-panel mesh, with streamlines.

Once the streamlines are generated, the user can run and extract the aerothermal data from S/HABP viscous level II analysis. The left image in Figure 7 illustrates the wall pressure contour plot generated by flying the configuration at Mach 12, angle of attack (AOA) 40 degrees; the right image depicts the contour plot for the radiation equilibrium wall temperature.

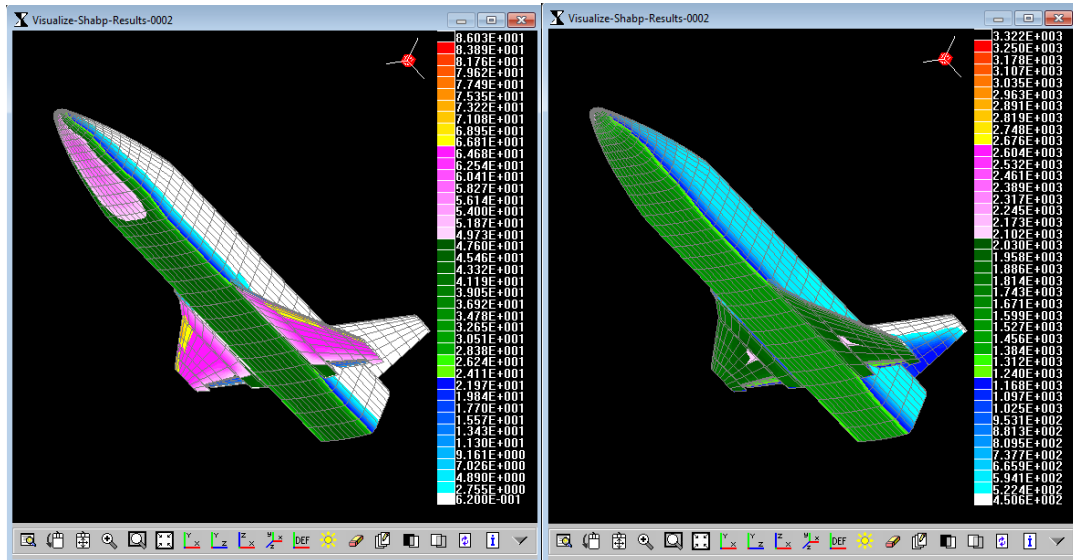


Figure 7. Left: wall pressure data at Mach 12, AOA 40. Right: radiation equilibrium wall temperature at Mach 12, AOA 40.

This data is generated and extracted for each control surface setting. A new class was developed that allows the user to run S/HABP and specify a trajectory file. *SHABP-WITH-TRAJECTORY-CLASS* allows the user to specify a grid-list and select trajectory points from a trajectory file. The file format is the one used by POST2 for Heat-TK. This file format can be generated by the *POST-TRAJECTORY-CLASS* in IDEA. For each point on the streamline, the following data is extracted: wetted distance, skin friction coefficient, heat adiabatic wall enthalpy, wall temperature, heat flux, and wall pressure. The data associated with each point can be formatted and presented to the TPS sizing code. Figure 8 illustrates the interface and the wall pressure associated with the nodes on streamline 12.

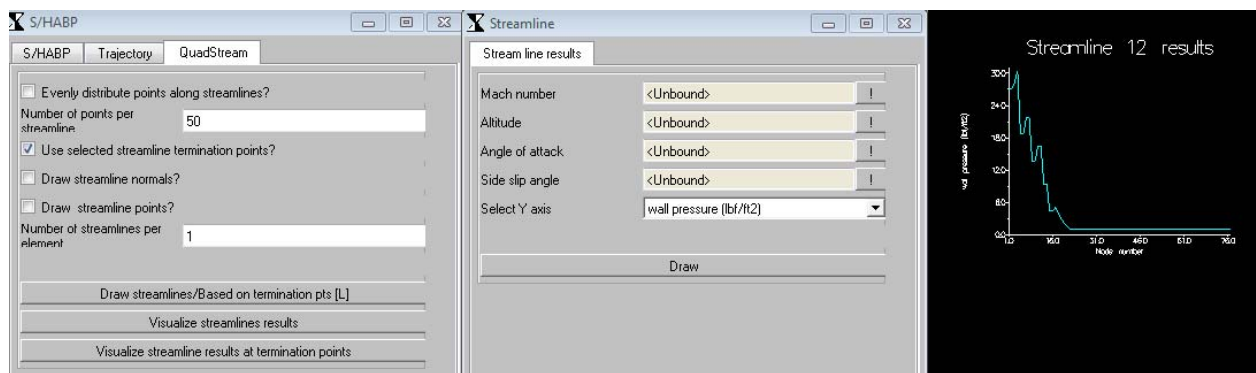


Figure 8. Wall pressure associated with the nodes on streamline 12.

CBAERO

Trajectory data from different sources needs to be integrated into different aerothermal and aeroheating codes; to achieve this goal a trajectory data interface class was developed. The *TRAJECTORY-DATA-FROM-FILE-TYPE-1-CLASS* allows the user to select an ASCII trajectory file. If the trajectory file in question has no labels, then the user can assign labels to the columns. Methods have been defined that generate data in the right format for use by different aerothermal, and aeroheating codes. Figure 9 depicts the interface associated with this class.

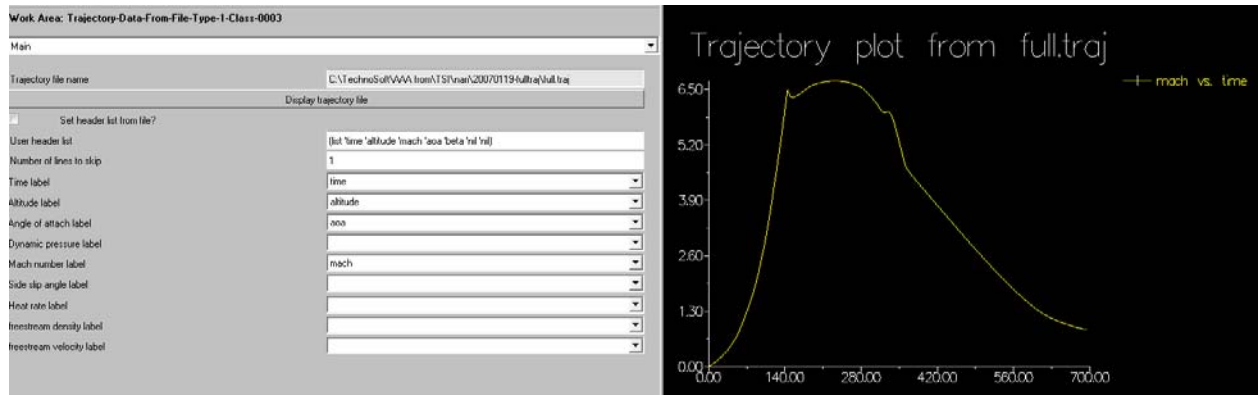


Figure 9. Interface form and sample data for the *TRAJECTORY-DATA-FROM-FILE-TYPE-1-CLASS*.

IDEA integrates CBAERO capabilities for generating streamlines and aeroheating data. A *CBAERO-ANALYSIS-INTERFACE-WITH-TRAJECTORY-CLASS* was developed with this goal in mind. The user selects an aero mesh and a POST-TRAJECTORY object or a TRAJECTORY-DATA-FROM-FILE object. Using the data from the mesh and the trajectory object a set of geometric and flight condition parameters (generate an aero database using cbaero to cover the flight regime) are populated. The data on the selected aerothermal points or the centers of each element are collected for use by the TPS sizing code. Figure 10 shows the top level interface form associated with the *CBAERO-ANALYSIS-INTERFACE-WITH-TRAJECTORY-CLASS*.

Work Area: cbaero-analysis-interface-with-trajectory-class-0001

Main

☐ Map node IDs to original node IDs?

☐ User center of mesh elements?

Space vehicle tps OML object: space-vehicle-tps-oml

Trajectory data object: post-trajectory

Surface elements object: surface-elements-query

Case name: "cbaero-run-5075"

Select aero thermal points [append/replace]

Draw OML

Draw selected grid

Draw/Undraw aero thermal points

Select analysis directory

Figure 10. Top level inputs to *CBAERO-ANALYSIS-INTERFACE-WITH-TRAJECTORY-CLASS*

Figure 11 depicts the streamlines generated from running cbaero-analysis-interface-with-trajectory-class instance.

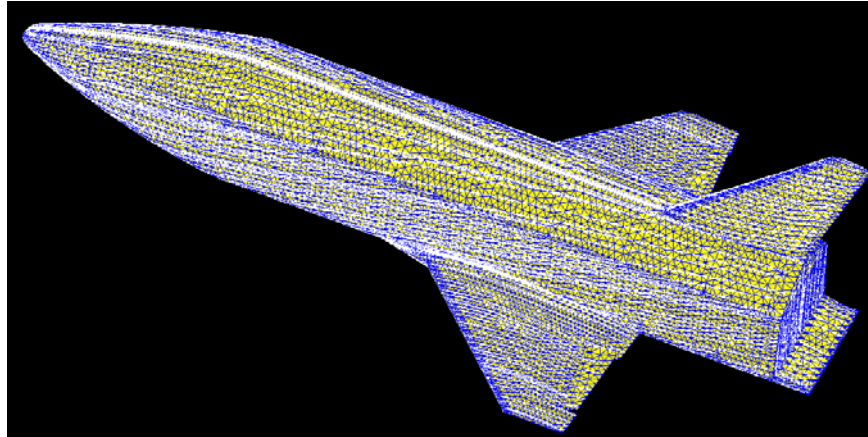


Figure 11. Streamlines generated from running CBAERO.

Figure 12 illustrates the convective Qdot contour plot generated using CBAERO at Mach 8 and angle of attack of 12 degrees.

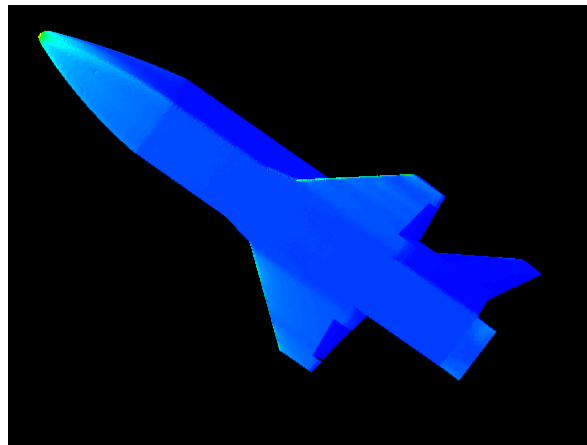


Figure 12. Convective Qdot contour plot at Mach 8, AOA 12 generated using CBAERO

PREMIN/LANMIN

Working with Kathryn Wurster and Janelle Born from Langley Research Center, a PREMIN and LANMIN interface was developed allowing the user to generate an aerothermal database for use by TPS sizing codes. The vehicle geometry is discretized by generating points on the vehicle. Each point on the vehicle is able to compute certain geometric parameters required by the PREMIN/LANMIN analysis codes. PREMIN and LANMIN runs are performed on each point on the vehicle separately generating aerothermal environment for each point, the geometric data needed by PREMIN and LANMIN are computed from the geometric model and fed into the

analysis model. The points on the vehicle are grouped into patches based on geometric criteria. The patches are grouped into patch-groups based on the analysis techniques associated with the patches in the group. For example, a patch group can be created to group the patches that form the nose region. Forebody chine patches can be grouped and swept cylinder analysis technique can be selected and applied to all the patches in the group.

The analysis results from each analysis point in a patch are extracted. For each time step in the trajectory the data from the analysis point with the highest heating parameters is selected for that trajectory time step and is used as the aerothermal environment data associated with the patch at that time step. This generates an aerothermal environment that is associated with the patch, and that can be used to determine the appropriate TPS concept across the whole patch.

Figure 13 depicts a sample patch breakup; points are generated and associated with the different patches as illustrated in Figure 14. As depicted in Figure 14, each point is able to compute its running length, and local geometric properties are used to populate the geometric information needed by the analysis model. Figure 15 depicts patch grouping interface and the visualization results from of a group of patches.

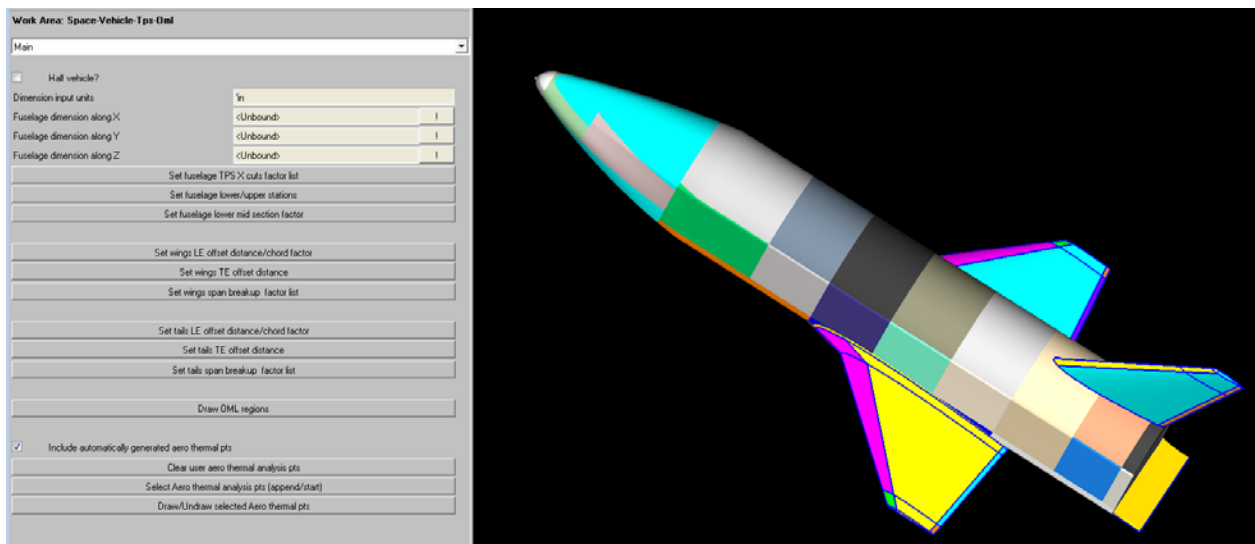


Figure 13. Patches are generated based on parameters defined by the user.

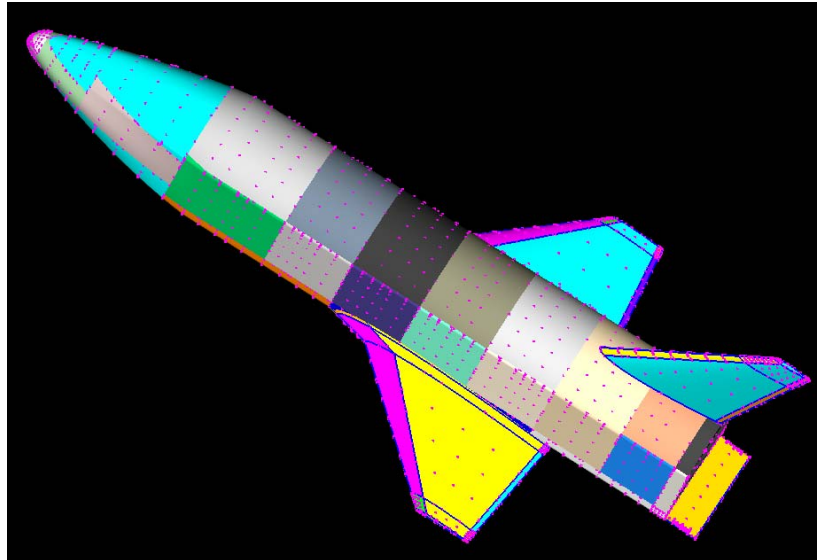


Figure 14. Points are automatically generated or selected by the user

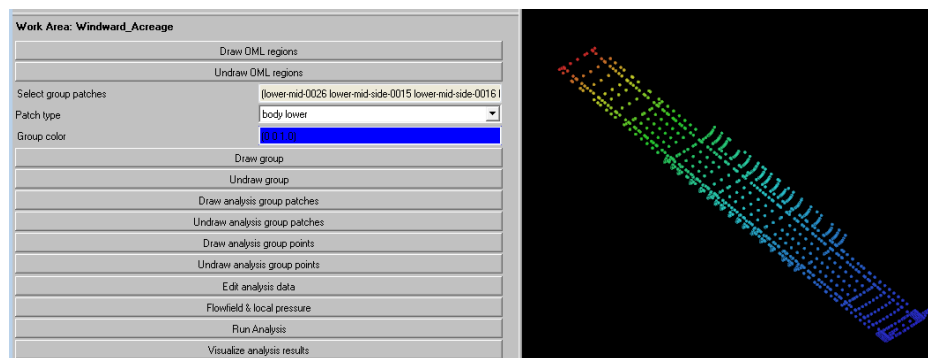


Figure 15. Qdot group visualization results.

TPS sizing (EXITS)

Working with Kathryn Wurster and Janelle Born from Langley Research Center, an EXITS analysis interface class was developed, allowing the user to perform TPS sizing on patches based on the aerothermal environment generated by any of the analysis codes described above. The main focus has been on using the aerothermal environment generated from running PREMIN/LANMIN. Data from the aerothermal, aeroheating environment object (point, or patch) is used by the EXITS interface object to perform TPS sizing. Data from running EXITS is extracted and used to determine whether the materials limit have been exceeded, min and max inner and outer temperatures, TPS weight, and structure weight per unit area. Figure 16 depicts the graphical user interface associated with output data from EXITS.

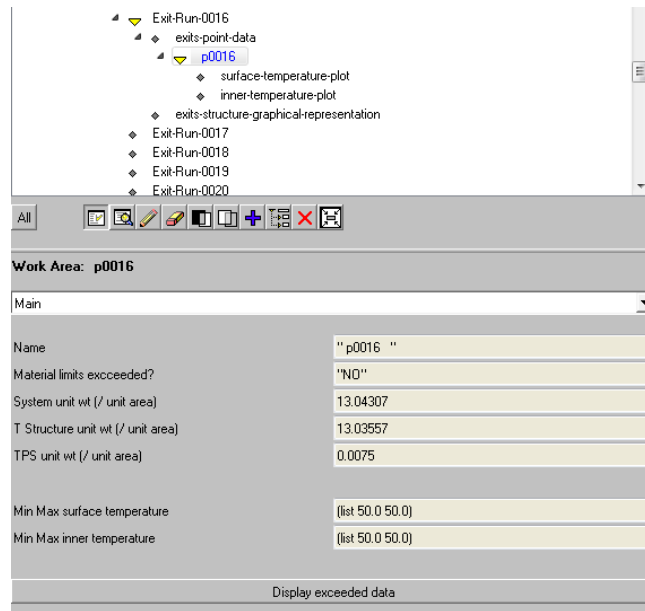


Figure 16. Output data from Exits.

Cart3D

Cart3D is a high fidelity inviscid analysis tool for conceptual and preliminary air vehicle design. Cart3D is package that consists of a number of utilities; IDEA utilizes a subset of the available utilities, namely *cubes*, and *flowCart*. *Cubes* is used to generate volume meshes from the surface meshes, and *flowCart* is the solver used by Cart3D. IDEA generates all the input files needed by Cart3D. The user can use a classified mesh query instance to facilitate force and moment accounting. Figure 17 depicts the vehicle body elements in green, the wing elements in magenta and the vertical elements in yellow.

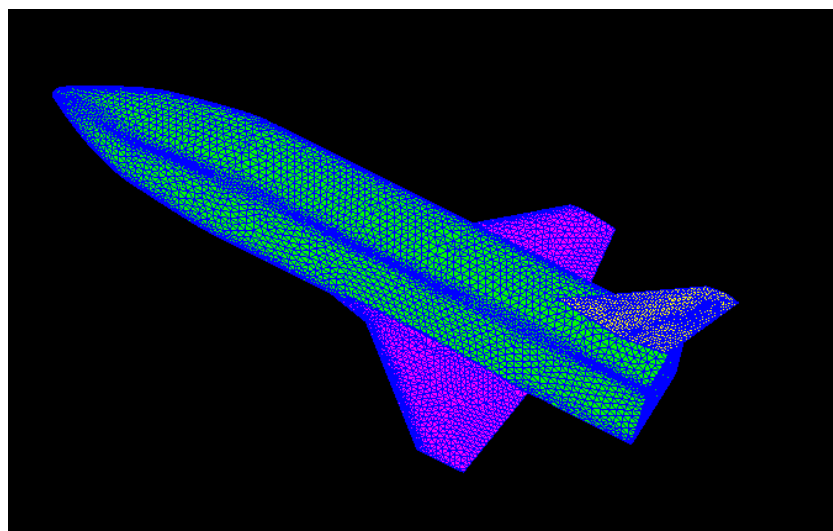


Figure 17. Classified mesh components.

Within IDEA the user can run Cart3D in two modes:

1. Adaptive meshing mode using *aero.csh*
2. Running *cubes* and *flowCart* where the volume mesh is not affected by the flight conditions.

Cart3D is run on a linux cluster. A TechnoSoft product, AMCRM (cluster run manager) is installed on the cluster and is the server that fulfills requests for Cart3D runs from IDEA sessions. Data is transferred seamlessly between server and clients.

Data is extracted from the runs and is used to populate the analysis model. Figure 18 illustrates the tree structure associated with Cart3D analysis instance and the pressure coefficient plot.

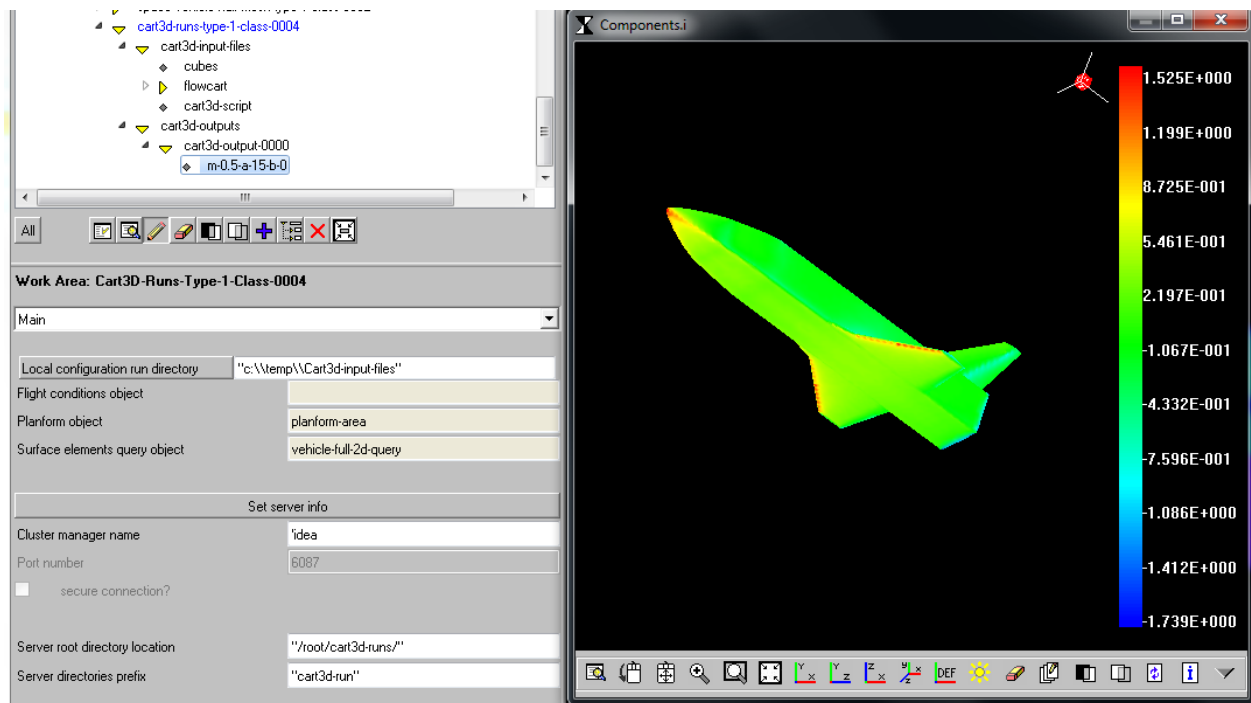


Figure 18. Cart3D analysis instance tree structure and results.

NPSS

Aspects of the Numerical Propulsion System Simulation (NPSS) code developed at NASA's Glenn Research Center have been integrated into IDEA. Working with Michael Seal from NASA Langley Research Center, an interface was developed that allows the user to run NPSS model from within IDEA to generate heat loads generated by the propulsion system on the body surface, side walls, and cowl. An *NPSS-INTERFACE-TYPE-1-CLASS* was developed to accomplish this goal. This class allows the user to specify a body-file-name (i.e. SRGULL_Body.DAT), and a cowl-file-name (i.e. SRGULL_Cowl.DAT). These files are generated by running SRGULL (a hypersonic propulsion code) already integrated into IDEA. These input files contain pressure, temperature, and Mach at axial locations along body and cowl. This data is interpolated and used to generate data for side-walls. The body, cowl and side-walls files are then used to run the NPSS model to generate the heat loads on body, cowl and side-walls.

The heat load files are then used to run a thermal management *SIMULINK* model. To accomplish this *TMS-MATLAB-SIMULINK-INTERFACE-TYPE-1-CLASS* was added to IDEA.

Concluding remarks

The new capabilities added to IDEA as a result of this task are imperative to allowing the users of the environment to perform Thermal Protection System studies in an efficient and effective manner using a variety of tools for generating the aerothermal, aeroheating environment data. This tool can also be used to compare the results from the different aerothermal / aeroheating tools and determine which methods are best suited for what conditions. The interface to NPSS is not fully generic; performing this task has provided valuable insight into how a generic interface can be designed and implemented.